AD-A020 681

PROPOSED REVISIONS TO ANSI STANDARD C95.1 FOR EXPOSURE TO RADIO FREQUENCY AND MICROWAVE RADIATIONS

James A. Wellsand

Army Materiel Command
Texarkana, Texas

November 1975

Report USAMC-ITC-02-08-76-410

PROPOSED REVISIONS TO ANSI STANDARD C95.1 FOR EXPOSURE TO RADIO FREQUENCY AND MICROWAVE RADIATIONS

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November 1975

Final Report

APPROVED FOR PUBLIC RELEASE:

DISTRIBUTION UNLIMITED

Prepared for

SAFETY ENGINEERING GRADUATE PROGRAM
AND TEXAS A&M UNIVERSITY GRADUATE CENTER
USAMC Intern Training Center - USALMC
Red River Army Depot
Texarkana, Texas 75501

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
USAMC-ITC-02-08-76-410

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
PROPOSED REVISIONS TO ANSI STANDARD C95.1 FOR EXPOSURE TO RADIO FREQUENCY AND MICROWAVE RADIATIONS

5. TYPE OF REPORT & PERIOD COVERED
FINAL

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
James A. Wellsand

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Safety Engineering Graduate Program
USAMC Intern Training Center
Red River Army Depot, Texarkana, TX 7550

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Safety Engineering Graduate Program
& Texas A&M University Graduate Center
USAMC Intern Training Center - USALMC

12. REPORT DATE
November 1975

13. NUMBER OF PAGES
66

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release: Distribution Unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Research performed by James Allen Wellsand under the supervision of Dr. W. L. Johnston, Professor, Industrial Engineering Dept., Texas A&M University

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electromagnetic radiation, ANSI standard C95.1

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper reviews the biological effects resulting from exposure to radio frequency and microwave radiations. The controversy over the relevance of the thermal and nonthermal effects is resolved in the light of present research findings. The quality of ANSI C95.1--Safety Level of Electromagnetic Radiation with Respect to Personnel--is examined. The basic conclusion is that the current guide number is acceptable. Proposals to improve the standard in other ways are made based on recent research.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT

PROPOSED REVISIONS TO ANSI STANDARD C95.1 FOR EXPOSURE TO RADIO FREQUENCY AND MICROWAVE RADIATIONS

by

James A. Wellsand

Accomplished as Part of the
AMC Safety Engineering Graduate Program
USAMC Intern Training Center

and

Presented in Partial Fulfillment of the Requirements of the
Degree of Master of Engineering
Texas A&M University
November 1975

FOREWORD

The research discussed in this report was accomplished as part of the Safety Engineering Graduate Program conducted jointly by the USAMC Intern Training Center and Texas A&M University. As such, the ideas, concepts and results herein presented are those of the author and do not necessarily reflect approval or acceptance by the Army.

This report has been reviewed and is approved for release. For further information on this project contact Dr. George D.C. Chiang, Chief of Safety Engineering, Red River Army Depot, Texarkana, Texas.

Approved:

Dr. George D.C. Chiang, Chief
Safety Engineering

For the Commander

James L. Arnett, Director, ITC

ABSTRACT

This paper reviews the biological effects resulting from exposure to radio frequency and microwave radiations. Thermal effects are the basis of the U.S. exposure standards for these frequencies. Nonthermal effects, as proclaimed by the Soviet Union, result at a much lower intensity. The controversy over the relevance of these effects is resolved in the light of present research findings.

The quality of the American National Standards Institute standard C95.1--Safety Level of Electromagnetic Radiation with Respect to Personnel--is examined. The basic conclusion is that the guide number of 10 mW/cm^2 is acceptable as the maximum recommended exposure level for prevention of human biological damage. Proposals are made for revisions to improve the effectiveness of the standard in other ways, based on recent research regarding biological effects.

ACKNOWLEDGMENTS

I would like to express my appreciation to Dr. W. L. Johnston for serving as my Advisory Committee chairman and for his assistance and guidance in making this paper a reality. I also extend my sincere gratitude to Daryl and Kathy Carpenter for the use of their typewriter for such a long time.

I especially thank my wife, Lynn, for her encouragement and her faith that enabled me to complete this research. She also deserves the credit for typing most of this paper.

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CHAPTER I

INTRODUCTION

In the last several decades there has been a tremendous advancement in the use of radio frequency and microwave propagations for many commercial, industrial, and military purposes. A natural and reasonable question to ask is what are the biological effects on the population at large resulting from exposure to these electromagnetic frequency bands, that previous generations were relatively unexposed to. The answer to this question must be understood in light of the fact that there are currently many radiated frequencies at a wide range of power levels in these bands, and there will continue to be more at an increasing rate keeping pace with today's expanding technologies.

It must be determined if there are deleterious health effects resulting from acute exposure to radio frequency and microwave fields, and at what incident power levels they occur. Just as important, it must be determined if there are any effects from chronic exposure that may affect and injure our future health or that of coming generations. The objective of this research report is a detailed study of the effects on the human biological system resulting from the exposure to radio frequency and microwave fields such that an assessment of both the American and Eastern European (including Russia) standards can be made for comparative

purposes and a proposal for revisions to the American National Standards Institute (ANSI) standard C95.1 can be formulated.

Quantifying Radio Frequency and Microwave Radiations

For the purpose of quantifying radio frequency and microwave radiations it is useful to illustrate their location in the electromagnetic spectrum, which covers a wide range of frequencies. Table I displays the entire spectrum and labels this portion of it. Radio frequency waves range from 30 kilohertz (kHz) to 30 megahertz (MHz) in the frequency spectrum (10,000 meters to 10 meters in wavelength). Microwaves range from 30 MHz to 3000 gigahertz (GHz) (10 meters to 1 millimeter). Table II illustrates the broadcast divisions of these bands.

In further quantifying these bands, it is necessary to discuss their inherent energy levels. These radiations transmit energy by electromagnetic waves. The photon energy corresponding to a radiation varies proportionally with the frequency of the wave. In fact, the photon or quantum energy level equals $h\nu$, where h is Plank's constant and ν is the frequency of the radiation. Since $h = 6.6256 \times 10^{-34}$ Joule-second and 1 electron-Volt (eV) $= 1.602 \times 10^{-19}$ Joule, the photon energy level is $4.136\nu \times 10^{-15}$ eV.

For radio frequency waves the photon energy level ranges from approximately 1.24×10^{-10} eV to 1.24×10^{-7} eV. For microwaves the energy level per photon ranges from about 1.24×10^{-7} eV to 1.24×10^{-3} eV. Both are classified as

TABLE I

THE ELECTROMAGNETIC SPECTRUM

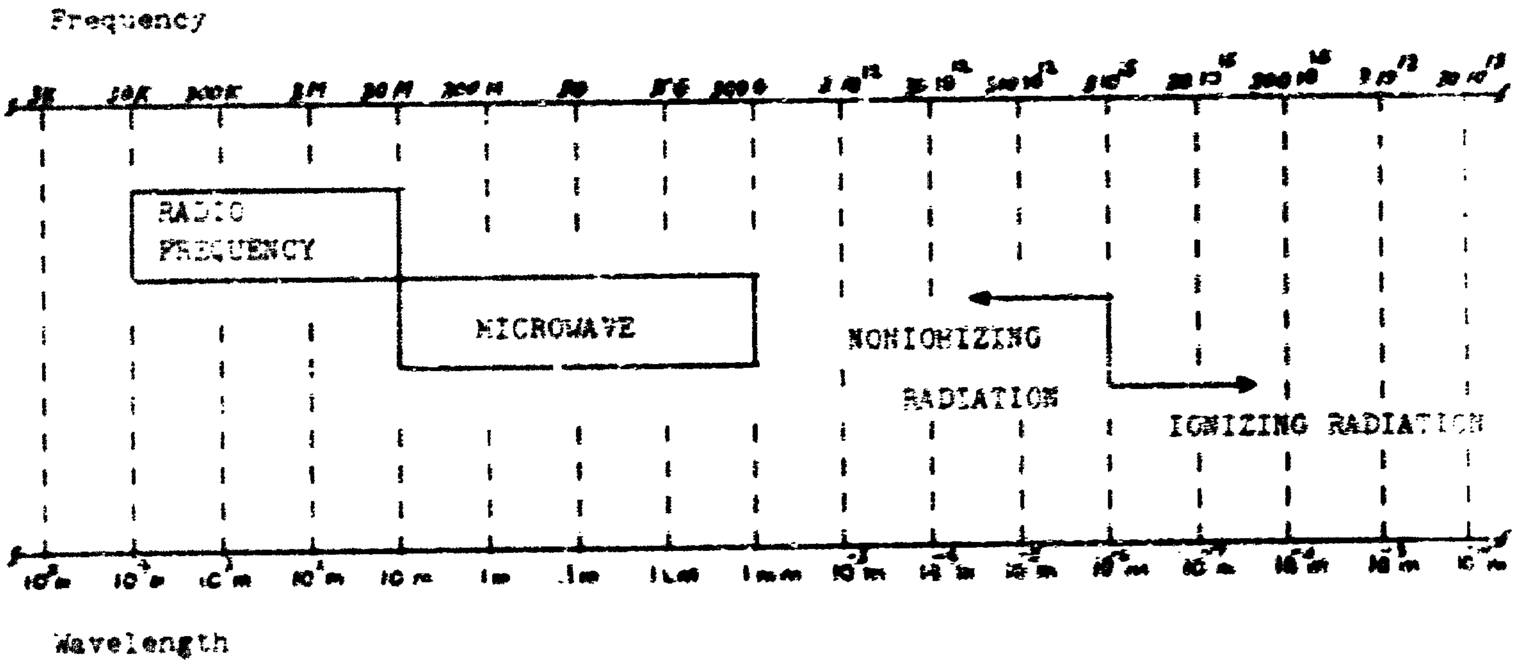

TABLE II

THE BROADCAST SPECTRUM

Designation	Frequency Range
LF (Low Frequency)	30k-300kHz
MF (Medium Frequency)	300k-3MHz
HF (High Frequency)	3M-30MHz
VHF (Very High Frequency)	30M-300MHz
UHF (Ultra High Frequency)	300M-3GHz
SHF (Super High Frequency)	3G-30GHz
EHF (Extremely High Frequency)	30G-300GHz

nonionizing radiations. Nonionizing radiation is categorized as those waves which do not sufficiently have the energy level required to ionize atomic oxygen and hydrogen, which is approximately 10-12 eV. In biological considerations, 12 eV is generally accepted as the cutoff level between nonionizing and ionizing radiations. (14)* As shown in Table I, the frequency in the spectrum corresponding to this energy level is roughly 3×10^{15} Hz.

Uses of Radio Frequency and Microwave Radiations

The uses of radio frequency waves and microwaves have been varied, and there are continuing to be new applications. They have been employed in radio and television broadcasts, communications, radar, microwave ovens, and microwave heating in industry and the medical profession. In standard AM radio broadcast, the frequency band is from 535 kHz to 1605 kHz with 107 station locations at 10 kHz intervals. They operate at maximum transmitter powers up to 50 kilowatts. FM stations operate in the band from 88 MHz to 108 MHz, such that there are 100 station allocations at 200 kHz spacing. The maximum allowable effective radiated power (ERP) is 100 kilowatts. From 1945 to February 1, 1971, the growth in radio broadcast has been 750 per cent, with 930 stations in 1945 and 6976 stations in February of 1971. (31) This phenomenal growth rate in radio broadcast has been one factor in the increasing

* The numbers in parentheses refer to List of References

exposure to these radiations. The distribution of the stations throughout the country is somewhat denser on the eastern part of the country. (7)

Current Federal Communications Commission (FCC) regulations permit television broadcasts on three bandwidths in two of the frequency designations in Table II. Two of them are in the VHF region of the spectrum. Channels 2-6 make up the low band, operating from 54 MHz to 88 MHz at a maximum ERP of 100 kilowatts. Channels 7-13 are the high band. They occupy the VHF region from 174 MHz to 216 MHz. UHF channels, including channels 14-83, occupy the region from 470 MHz to 890 MHz, and have a maximum ERP of 5000 kilowatts. All television stations have a 6 MHz bandwidth.

The growth rate of television has been extraordinary since the FCC legalized black-and-white broadcast in 1941. In 1945 there were only six authorized stations on the air. As of February 1, 1971, there were 892. People living in large metropolitan areas, where there is a heavy density of radio and television stations, are being subjected to all of these every day of their lives. The rising popularity of cable television is also contributing to greater use in microwave propagations because the cable programs are sent through the air to chosen areas where they are then further distributed by coaxial cable transmission.

There are many FCC allocations for two-way communications, divided into the following categories: marine, aeronautical, public safety, industrial, land transportation, personal, and

disaster communications. The allocations are too numerous to list here, but are spread throughout the radio frequency and microwave bands.

These waves are becoming more and more evident in our personal lives. Many Americans are experimenting with citizens band (CB) radios. With the rapidly expanding electronic technology, the convenience of owning a CB radio has become a practicality. Solid-state transceivers and auxiliary equipment require an investment of only about $150, and a license to start costs $4.00. In 1974 one quarter of a million licenses were issued. An FCC source estimates that CB sales are booming to such extent that there will be more than one million licenses issued this year. (5) To alleviate the congestion on the existing channels from flourishing sales and popularity of CB radios, the FCC has proposed to expand the number of communication channels from twenty-three to seventy and eventually to one hundred. CB radios do not transmit much radio frequency power, but they are an additional source of electromagnetic fields influencing our daily life. Their range under ideal conditions is only about twenty-five miles.

Another personal use has been that of microwave ovens. Operating at 2.45 GHz, these devices are being sold in greater numbers each year as consumers are discovering the speed and convenience of microwave cooking. 1975 sales to American consumers are estimated to reach 200,000 ovens. (1)

Industry and the medical profession have taken advantage of the thermal effects from microwave exposure for use in a variety of heat processes. The use of radar for both civilian and military applications is continuing to increase. Radar systems generally use microwaves in the 1 GHz to 30 GHz region. Long-distance telephoning is now seventy per cent beamed from station-to-station by microwaves. (10) A future application under consideration is the use of these waves in electrical power transmission. It would eliminate many of the vast networks of lines and towers now serving this purpose by beaming the converted electrical power to a relay satellite for transmission to receivers outside population centers. Thus, the radio frequency and microwave portions of the electromagnetic spectrum have many applications and uses in our lives today and will certainly be even more prominent in our future, but the original questions as to the health and safety of the population, being subjected to this electronic pollution, still remains.

Background Exposure Levels

Although considerable research has been done concerning the possible biological effects resulting from exposure to radio frequency and microwave propagations, the results have not conclusively settled the question as to what are the harmful effects and at what incident power levels they occur. The exposure limits to the more familiar ionizing radiations of x-rays and gamma rays are set to about ten times the

natural environmental background level; whereas, the current U.S. standard for exposure to the nonionizing radiations under examination in this paper exceeds the natural background level by a factor of 10^9. (1) The Eastern European countries and Russia believe there are harmful effects at as low as one-thousandth of the energy level specified in the U.S. standard.

Chapter II of this report will delve further into the present status of the question of the biological effects. The remainder of the report will be devoted as follows: Chapter III--to the research done on the thermal effects from radio frequency and microwave exposure; Chapter IV--to the background and results of the research done on the so-called nonthermal effects; Chapter V--to the comparison of thermal and nonthermal effects, their incident power levels, an evaluation of ANSI C95.1, and the results of the comparison used to propose revisions to improve the effectiveness of the U.S. standard; and Chapter VI--to the conclusions of the biological effects resulting from radio frequency and microwave exposure, to the role of the ANSI C95.1 standard in the United States, and to the effects in industry and the military resulting from the proposed revisions to the standard.

CHAPTER II

EXISTING EXPOSURE STANDARDS

The concern for the health and welfare of our citizens with regards to the possible biological effects from increased exposure to radio frequency and microwave fields has steadily developed over the past half century. This concern has parallelled the expansion of the technology and use of these bands. The initial concern was for our military personnel who served as electronic technicians and were responsible for the operation and maintenance of the military communication and radar equipment. They could feel the sensation of heat within their bodies when they happened to be exposed to a radiating transmitter beam. Furthermore, with the growth of radio and television broadcast, a widespread portion of the population was about to be exposed to new energy levels of this region of the electromagnetic spectrum.

The earliest research that had been previously performed in this area demonstrated the effects of thermal stress in the test organisms from exposure to a high frequency capacitive field. In 1924 Schereschewsky found that tissue heating of up to approximately 44°C (111.2°F) caused death in mice. (27) He noted a similar increase in body temperature in human test subjects. Carpenter and Page produced 105°F (40.5°C) artificial fevers in humans with the use of this energy

source. (2) Prior to 1940, however, most research that had been conducted considered molecular and chemical effects on elemental biological systems. After World War II a new emphasis was put into the nonionizing radiation effects research. Whole body irradiation experiments in various test animals and humans were being performed.

Currently, there are two schools of thought about the biological effects resulting from radio frequency and microwave exposure. The United States and many other Western countries have established their exposure standards based on the opinion that "thermal effects are considered to be the most harmful and therefore have been used as the basis for establishing the levels," as specified in the ANSI C95.1 standard. (26) Thermal effects understandably result from energy considerations as the dissipation of energy as heat by increasing the kinetic energy in the absorbing tissue.

The Russians and some Eastern European countries have based their exposure standards upon the premise that certain nonthermal effects occur at much lower intensities than that which ANSI recommends as safe. Such effects are mainly those upon the central nervous system. There has been much controversy among American scientists regarding the relative merit of the Russian claims of nonthermal effects. (32) A basic problem that still exists is the lack of complete and thorough knowledge of certain biological functions, such as nerve excitation and conduction. The theoretical interaction mechanisms between the alternating electromagnetic field and

biological functions have not been satisfactorally explained. Neither has the theoretical wave configuration within the tissue. This has greatly hampered formulating a rational basis for the existence or not of many of the hypothesized nonthermal biological effects.

Formulating an Exposure Standard

Before proceeding with a summary and discussion of the exposure standards now deemed as the acceptable maximum exposure limits allowable, it is appropriate to examine the philosophy and practicality of setting such a standard. Ideally, in setting an exposure standard for physical agents such as these, a dose-response relationship must be determined for any acute effects that would occur. After this is completed, further examination must be done concerning the possibility of late-arising harmful effects from low intensity chronic exposure. It is a time-consuming and difficult process.

Since the scientific-approach method of forming a theoretical solution to determine the nature and degree of this problem of conceivable biological effects has not yet been found, reliance upon empirical evidence has been necessary. Experiments involving the question of deleterious effects in man rule out any initial possibility of human subjects. The research into the dose-response relationships of various radio frequency and microwave source configurations on different tissue geometries leading to irreversible or lethal effects

has been performed on various animal species. It is obvious from the start that there will not be a clear-cut relationship between exposure level and physiological effect, because of the many variables in both the electromagnetic radiation sources and the tissue structure of the body. Threshold values are determined in various species for the observed effects. Careful analysis and extrapolation can then provide a guess for human threshold values under varying conditions such as frequency, plane of polarization, mode of modulation, time of duration, body surface area exposed, and status of the individual with respect to clothing worn, his thermal stress, and environment. A numerical value implies both the effect and stress are measurable. (16)

The standard exposure limit value is considered a guideline because no sharp demarcation exists between effect and no effect. The effect must reflect the nature and seriousness of the injury along with the body's adaptive and recovery rates. Effects that are not acute under controlled conditions will allow for human study. Under these conditions, human data can aid in setting threshold values and safety factors for determination of an exposure limit for the protection standard.

Injurious effects might result from the final irreversibility of a reversible process that has occurred many times, or as the consequence of cumulative effects from repeated or constant radio frequency and microwave exposures over an extended period of time. Such effects might be totally

unrelated to the harmful effects resulting from acute short duration exposures. Continued research in this area must conclusively deny the possibility of this occurrence, but overprotection without justification would put undue restriction on our occupational and social lives.

Summary of Existing Standards

The American National Standards Institute (formerly the American Standards Association) formulated the first commercial United States standard for exposure to frequencies within the radio frequency and microwave bands of the electromagnetic radiation spectrum. Under the sponsorship of the Department of the Navy and the Institute of Electrical and Electronic Engineers, the Radiation Hazards Project was approved in 1960. Its scope was to identify the hazards associated with electromagnetic radiation in the 10 kHz to 100 GHz range. It was felt that these would affect man, volatile materials, and explosive devices. The committee to coordinate the project consisted of six subcommittees, one of which was the subcommittee for "Safety Levels and/or Tolerances with Respect to Personnel." This subcommittee was directly responsible for the ANSI C95.1 standard--Safety Level of Electromagnetic Radiation with Respect to Personnel, first published in 1966 and recently revised on November 15, 1974. The revision was minor and clarified the purpose and applicability of the standard. (26) The levels recommended as guidelines in this standard serve as "recommended radiation

protection guides to prevent biological injury from exposure to electromagnetic radiation." (26)

ANSI C95.1 recommends a maximum exposure of 10 milliwatts per square centimeter (mW/cm^2), with the equivalent free space electric field (E) and magnetic field (H) strengths approximately equal to 200 volts per meter (V/m) and .5 amperes per meter (A/m) rms, for continuous wave (cw) radiation under normal environmental conditions. (26) For modulated wave sources, over any .1 hour period, none of the following should be exceeded:

Mean Square Electric Field Strength- 40,000 V^2/m^2
Mean Square Magnetic Field Strength- .25 A^2/m^2
Power Density- 10mW/cm^2
Energy Density-1mWh/cm^2 (26)

The standard explains that this is one source of heat input to the body. The thermal stress a person can safely withstand varies mainly with his thermal environment, clothing worn, and degree of physical labor. Taking these factors into consideration is necessary, so the standard warns that the guide levels must be adjusted accordingly. It also warns against the susceptibility of people with circulatory difficulties and certain other ailments to the thermal stress involved. The standard is a protection standard, thus is not intended for deliberate exposures for medical purposes. The quality of this standard will be assessed in Chapter V in view of the thermal and nonthermal effects to be discussed in the next two chapters.

The radio frequency and microwave exposure standards for

Russia and several Eastern European countries are listed in Table III. Their basis upon nonthermal effects has caused them to have threshold values at much less intensity levels than those by which thermal effects occur.

With a surface look at the existing exposure standards, one might surmise that the Russians and their counterparts either have a different standard of measurement or know something we don't. The incongruity between standards exists though because the biological effects that are their basis for foundation are entirely different. They result at different incident power levels and their observance constitutes two different experimental approaches. Western scientists determine the upper limit of the no-effect dose by detecting a physiological or biochemical change in the subject. On the other hand, the Russians and their collaborators detect behavioral or pyschological changes in their subjects to set their standard by. Standards setting, to limit the amount of radiation individuals can accept with safety, carries a heavy impact on the use of these radiant energies. All avenues of possible harmful biological effects must be considered.

TABLE III

SUMMARY OF RUSSIAN AND EASTERN EUROPEAN STANDARDS

FOR EXPOSURE TO RADIO FREQUENCY AND MICROWAVE RADIATIONS

Country	Radiation Frequency	Maximum Recommended Level	Remarks
U.S.S.R.	.1 to 1.5 MHz	20 V/m 5 A/m	Alternating magnetic fields
	1.5 to 30 MHz	20 V/m	
	30 to 300 MHz	5 V/m	
	>300 MHz	10 μW/cm^2 100 μW/cm^2 1 mW/cm^2	6 hr/day 2 hr/day 15 min/day
CZECHOSLOVAKIA	.01 to 300 MHz	10 V/m	8 hr/day
	>300 MHz	25 μW/cm^2	8 hr/day CW radiation
		10 μW/cm^2	8 hr/day Pulsed radiation
POLAND	>300 MHz	10 μW/cm^2 100 μW/cm^2 1 mW/cm^2	8 hr exposure/day 2 to 3 hr/day 15 to 20 min/day

CHAPTER III

THERMAL EFFECTS OF RADIO FREQUENCY AND MICROWAVE RADIATIONS

The earliest known and most obvious of the biological effects resulting from exposure to radio frequency and microwave radiations were those of a thermal nature. The photon energy level associated with this region of the electromagnetic spectrum is far too low to ionize or cause ionization of molecules in the body, no matter how many quanta are absorbed. The kinetic energy contained in the wave that is absorbed by the biological tissue will be transformed into kinetic energy in the medium as a result of the oscillatory and rotational motion of water and protein dipole molecules trying to align themselves with the electric field component of the wave. The increased motion of the molecules and the resulting additional molecular collisions cause a temperature rise in the tissue. The absorption efficiency dictating how much energy is actually absorbed is dependent upon the electrical characteristics of the tissue and the cross-sectional area involved.

Medically Beneficial Thermal Effects

All thermal effects are not harmful to mankind. In fact, there are medically beneficial thermal effects. The

oldest known of these is diathermy, which is a therapeutic technique using microwaves for deep penetration of heat. The frequencies of 27.12 MHz, 915 MHz, and 2.45 GHz (the same frequency used in commercial microwave ovens) are used in diathermy treatments in this country. Localized temperature rises to 43-45°C (109.4-113°F) are typical. Under controlled conditions power levels of 590 mW/cm^2 are used. (11) The physiological effects of this treatment are numerous, including increased blood flow by capillary dilation, relaxation of muscle spasms, and temporary increases in pain thresholds.

The medical profession is currently using the microwave thermal phenomenon of deep penetration in tissue for several modern techniques. Selective tissue heating of tumors in cancer treatment with the surrounding tissues in a hypothermic state allows the growth to readily absorb a chosen toxic drug designed to kill it. Experiments on mice have shown that seventy-five per cent of the tumors disappeared after four to five hours of treatment. (11) Refrigerated blood can now be warmed quickly from its storage temperature of 4-6°C (39.2-42.8°F) using microwaves, to permit faster transfusions than by previous methods. A blood warmer developed by Restall will heat the blood to 35°C (95°F) in one minute. (11) Other cryopreserved biological substances and organs can be rapidly thawed using microwave techniques, thus increasing survival rates by increasing thawing rates over previously used methods. As a last example, greater success has been

accomplished in open heart surgery due to the better warming techniques of microwave heating. Body temperature is reduced to slow down the metabolic rate to allow the heart to be stopped during surgery. With carefully controlled microwave exposure, biological effects have profound medical value.

Factors Determining the Degree of Thermal Response

Biological effects from uncontrolled and overexposed partial or whole body irradiation are harmful when the body's normal metabolic rate is interferred with. Radio frequency and microwave exposure induce heat stress, and can be regarded as another form of thermal input to tax the body's thermo-regulatory system. When this homeostatic mechanism is exceeded, cell and tissue damage will occur. Thermal effects can be thought of as an artificially induced fever.

Numerous factors are involved in determining the amount of thermal stress induced. The properties of the wave certainly affect the amount of energy absorbed by the tissue. The interface phenomena of reflection, refraction, scattering, polarization, and absorption depend upon the interaction of the wave and tissue. Of these absorption, reflection, and refraction are more important. The cross-sectional area of the irradiated tissue in comparison to the frequency of the wave is also a significant factor. Lastly, the body's ability to sense and respond to the stress must be examined. These three factors will now be examined more closely to determine the significance of their influence on the relative magnitude

of thermal stress imposed.

The absorption of radiation is nonuniform and is dependent upon the dielectric properties of the tissue. Generally, absorption is high and the depth of penetration is shallow in tissues with high water content like skin, muscle, organs, and brain. Absorption is about a magnitude lower for low water content tissues like fat and bone. (11) The electrical properties for practically all tissues have been studied and numerical values have been determined that have been used quite effectively in phantom modeling. The parameters of interest are the dielectric constant ϵ, the specific resistance ρ, and the relative permeability μ. Although the first two vary considerably depending upon tissue type and content, their ranges in the microwave region in living tissue are 5-70 for ϵ and $10-10^4$ for ρ. (4) The propagation of electromagnetic radiation within the tissue and at boundaries of dissimilar tissues is dependent upon these three parameters. The phenomena of reflection and absorption of the wave are frequency dependent because ϵ and ρ are. As a result, the thermal biological effects from radio frequency and microwave radiations are clearly a function of the incident frequency of the wave.

Absorption coefficients and depth of penetration have been calculated from the electrical properties of the tissues and verified in clinical studies. For frequencies less than 1 GHz to 3 GHz about forty per cent of the incident energy is

absorbed by deep tissue, and above the frequency range the absorption is for the most part in the skin. (3) According to Wilkening, for waves of 150 MHz and less the human body is believed to be essentially transparent. (33) Frequencies of 150 MHz to 1.2 GHz, he states, penetrate the "greatest with the potential of causing damage to internal body organs." From 1.2 GHz to 10 GHz, penetration is not as deep (only 1 mm to 1 cm). Above 10 GHz penetration is negligible and the outer skin surface absorbs these frequencies. Absorption coefficients of these higher frequencies are similar to those in the infrared region of the spectrum. (3)

Tissue interfaces represent a change in the absorbing medium such that wave reflections are likely to occur. "Hot spots" are likely to occur at interfaces of high and low water content tissues. (11) Since not all of the incident power is transmitted, the reflected power sets up standing waves in preceding tissue. The standing waves are similar to those occurring in transmission line theory. In a shorted transmission line the voltage is a minimum at the shorted end. When a wave passing through a tissue of low water content reaches a tissue of high water content, the intensity of the power density is a minimum as a standing wave is set up from the reflected portion of the wave, which is 180° out of phase with the incident wave. The high water content tissue must be at least as thick as its depth of penetration. In an open ended transmission line, the voltage is maximum at the termination. In the reverse situation where a wave is traveling

through the tissue of high water content first, the amplitude of the reflected wave is in phase with the incident wave setting up a standing wave with a maximum intensity at the interface of the dissimilar tissues.

The cross-sectional tissue area irradiated significantly affects the biological effects generated. The area is dependent upon tissue conductivity, the thickness of the fat layer for impedance matching, and naturally the physical dimensions that are irradiated. Cross-sections that are small compared to the wavelength are particularly susceptible to absorbing higher doses through increased absorption efficiency. This is assuming that the tissue is in the far field region of the propagation.

The far or radiative field region implies that the distance from the source is great enough such that an absorbing object placed in the field does not alter the field and that the power density decreases with increasing distance according to the inverse square law. These assumptions are not valid in the near or inductive field of the propagation, which is quantitatively described as the region lying about one wavelength from the source antenna extending to a distance that is equal to the square of the largest aperature dimension of the antenna divided by the wavelength. The source beam is formed here.

The electric field component and the magnetic field component of the wave are not related as a simple

proportionality as they are in the far field with each being mutually perpendicular and perpendicular to the direction of propagation of the wave. Since there is an interaction in the near field, the flux is not predictive as in the far field. Therefore, the energy concept of power density is not accurate in the near field. A measurement of the intensity of the wave in the near field must be made then in terms of the electric field component in volts per meter to characterize the wave. Much of the radio frequency portion of the spectrum must be measured this way due to their considerably longer wavelength than the microwave portion. The absorption characteristics previously discussed were such that the tissue was implied to be in the far field of the source radiation. The absorption characteristics in the near field are much more difficult to determine because of these concepts.

The last consideration in determining the heat stress induced concerns the tissue, organ, or area of the body that is exposed. Exposure may be considered as either partial or whole body irradiation. Obviously, the duration and intensity of exposure are important variables for consideration of temperature rise in the body. The tissue properties and wave frequency have been previously discussed. The part of the body exposed is a significant variable to consider for a determination of temperature rise because different parts of the body vary in the ability to sense thermal stimulation and also to respond to a thermal influence. The degree of

innervation and vascularization determine the body's response to these two imposing conditions.

Areas where there are greater numbers of neural receptors reflect a greater sensitivity of the tissue to a thermal stimulus. Thermal regulation of the body depends upon this principle. In highly vascularized tissues, the flow of blood proves to be an excellent heat exchanger through conduction and convection. Thus, the most susceptible parts of the body are those that are not as well protected by these physiological phenomena. Such areas include the eye lens, testes, gall bladder, and parts of the gastrointestinal tract. It has been shown that damage to these tissues can occur without significant rise in oral or rectal temperature. (11)

The importance of the circulation as a means of thermoregulatory control should not be minimized. In partial body exposure thermal stabilization will occur at higher incident power density levels. Blood flow will carry the thermal energy to cooler areas of the body. Excitation above the ability to regulate temperature through the circulatory system and sweating mechanism will cause a temperature rise in the effected area. Experiments have shown that for frequencies between .2 GHz and 24.5 GHz, an exposure to a power density level greater than 100 mW/cm^2 for an hour or more have thermal pathophysiological manifestations, and at less than 100 mW/cm^2 there were no pathophysiological changes. (17) Conveniently, as the frequency of the radiation and its

associated photon energy increases, the depth of penetration decreases allowing the highly capillarized tissues to more effectively dispose of the heat.

Animal experimentation has shown that the heat input from radio frequency and microwave exposure will be diagnosed as having the typical symptoms of hyperthermia. The resulting thermal damage is generally indistinguishable from that resulting from a fever. (15) Dilution of the blood appeared as an early sign of acute heat stress. Vasodilation was the reason for this manifestation. Dehydration developed after considerable exposure. Other documented physiological effects of heat stress in humans include: denaturing and coagulation of proteins, decrease in enzyme activity, increased permeability of cell membranes, and functional impairment of the nervous system. At a temperature of approximately 41°C (105°F) the central nervous system stops functioning normally. (9)

In 1953 Schwan recommended to the Navy that the standard for radio frequency and microwave exposure be set at 10 mW/cm^2. His research lead him to believe that 100 mW/cm^2 was the power density required to cause a significant temperature rise in human beings. He applied a safety factor of ten to bring about his recommendation. Schwan found no evidence at all of significant thermal effects at that power density level. (28) At 10 mW/cm^2, Mumford indicated that 57.5 watts will be absorbed under certain specified conditions of cross-sectional area in a standard man. (18) This can be compared to the

basal metabolic rate of 100 watts for a person engaged in light work and 300 watts for a person working heavily. (33)

With more than two decades of investigation in clinical and laboratory studies, individuals even with many years of occupational microwave exposure have shown no adverse health effects by staying within the prescibed exposure standard. (17) The only documented health problems from the thermal effects of these radiant energies have been attributed to cataracts from overexposure. Over eighty-two cases have been documented. Hirsch and Parker reported forty cases and Zaret reported forty-two subsequent cases. (4)

CONCLUSIONS

There has been extensive research done on the thermal effects of radio frequency and microwave exposure to examine both the beneficial and harmful results in our species. Exposure under specified and controlled conditions has been used successfully in the medical profession for diagnostic and therapeutic purposes. Cited examples have shown that the profession owes many credits to this band of the spectrum for its unique ability to penetrate skin and subsequent subcutaneous layers to heat the deeper tissues.

In uncontrolled and overexposed situations, humans risk the possibility of mild thermal stress and even cell and tissue damage without the respective level of heat sensation in the skin. The heat sensitive neural receptors in the skin would be passed over due to the impedance matching

characteristics of the outer tissues. The body's biological response is similar to other modes of heat stress. If the thermoregulatory system is not overtaxed, then acute biological effects probably will not result.

Careful attention must be paid to parts of the body less sensitive to heat and also less protected by the thermoregulatory system. The particular sensitivity of the eye to cataract formation from thermal inducement by these radiations has been well documented. The actual pathophysiological phenomena observed are generally indistinguishable from other sources of hyperthermia. Although specific and detailed examination of the structural and functional changes of the eye, testes, or even any selective tissue has not been included, this chapter has portrayed a basic overview of the thermal nature of the interaction of the human biological system and the radiations in question.

CHAPTER IV

NONTHERMAL EFFECTS OF RADIO FREQUENCY AND MICROWAVE RADIATIONS

The category of biological effects resulting from exposure to radio frequency and microwave radiations that occurs without the existence of thermal influence is classified as nonthermal effects. Implied in this definition is the understanding that for an effect to result without tissue heating, the incident power density level must be lower than that which would be necessary to cause such a caloric effect. An intensity of 100 mW/cm^2 was determined to produce pathophysiological thermal effects after a short duration of an hour or so. (17) Thermal effects within the body's capability of homeostatic response result from only the higher frequencies in this region of the spectrum at intensities as low as the United States standard of 10 mW/cm^2. Studies have shown that as much as a 1°C temperature rise will result at this intensity of radiation. (18) Under these considerations then, nonthermal effects are specifically associated with power density levels less than this.

Reversible and Specific Nonthermal Effects

The U.S.S.R. and several Eastern European countries have claimed an existence of nonthermal effects based on symptoms

observed in occupationally exposed workers. Their scientists have reported behavioral alterations and functional changes in the central nervous system using conditional reflexes as an endpoint in their investigations. Eastern standards have been based on these studies. The Russians originated the basic standard level that the Eastern Europeans have accepted. In 1959 the Russian Ministry of Health promulgated the maximum recommended protection exposure levels shown in Table III in Chapter II. Petrov and Subbota have substantiated Soviet standards by explaining that some effects occur at 1 mW/cm^2, based on animal studies. (20) For a ten hour work day the exposure is thus reduced to .1 mW/cm^2. A safety factor of ten is specified so the maximum recommended exposure level is .01 mW/cm^2, which is the present Russian standard.

Soviet research is based on Pavlovian "nervism," in which the "central nervous system exerts a controlling influence over all types of reactions in the organism, including various local tissue reactions. Nonnervous reactions are considered as only of secondary importance because the basic controlling role of the central nervous system in the whole organism. Thus, in considering microwave pathogenesis, Soviet physiologists have persistently sought the central nervous system mechanisms that might be responsible for each microwave-induced phenomenon." (6) With this basis for thinking the central nervous system is necessarily the most sensitive to these energies of all body's organs and systems. The cardiovascular

system is also susceptible to nonthermal effects. The Russians have theorized that there are reversible and specific nonthermal biological effects from exposure to these radiant energies. Reversible effects are functional changes that usually arise after longer periods of irradiation. Specific effects result from interaction of the radiation with special radio frequency and microwave sensitive receptors within the body.

Physiological manifestations that were detected involved the following reversible effects:

a) hypotension,
b) bradycardia,
c) excitation of the thyroid gland,
d) changes in the endocrine-humeral processes,
e) inhibition of conditioned-reflex activity,
f) and interference in interneuronal connections in the brain.

Biochemical changes reported were increased blood histamine levels, decreased cholinesterase, and RNA changes. Specific effects noted were elevations in the thresholds of the olfactory and auditory senses. (4)

In a U.S.S.R. study by Letavet and Gordem microwave workers reported a greater incidence of complaints of headache, irritability, and drowsiness than a controlled group of non-exposed workers. (13) Other symptoms in Soviet studies are eyestrain, diminished intellectual capabilities, dullness, partial memory loss, decreased sexual ability, insomnia, shortness of breath, and chest pains. (21) Presman, one of the more published Soviet investigators on

this subject, has stated that these alterations in body activities and associated clinical symptoms are reversible as a general rule, after the exposure had ceased. (21) The recovery period ranged up to several weeks. The type and amount of effect was dependent on wave phenomena and area of the body exposed. The nature of the reversible effect generally did not depend on either the wavelength or intensity though within the range of 3-300 GHz at hundreths to several units of milliwatts per square centimeter. (21) Outside of this range, however, vagotonic reactions generally increased in nature and the central nervous system effectiveness decreased by increasing frequency, and both phenomena occurred to a greater degree with increased intensity. (21)

Presman stressed that the reversible nature of nonthermal biological effects could definitely be retarded. Initial exposure to these radiations results in an adapting response by the body. Further exposures aggravate the situation such that the nonthermal effects surface and become evident. This is the resistance phase. Continued exposure can bring on an exhausting phenomena associated with the effect. Such a concept was submitted in this country by Zaret in his research that elastic membranes in the body, continually responsible for many physiological functions, could fatigue. (34) This hypothesis has not satisfactorally been substantiated yet though.

The Russian claims have not been theoretically expressed concerning the interaction mechanisms responsible for the effects. Presman has proposed that the interference with the functioning of the central nervous system may result from increased excitation of nerve cells by affecting the cell membrane, influencing the sodium-potassium gradient between the cell and extracellular fluid, or changing the cell membrane's permeability by producing oscillation among water molecules bound to protein molecules in the membrane and water molecules in the local tissue.

The prominent specific effect discussed in Soviet writing is that of the loss of sensitivity of the sense of smell. The olfactory sense has shown a significant reduction in capability in studies done on both laboratory animals and man. (22)

U.S. Research on Nonthermal Effects

Research performed in the United States has not substantiated the Russian claims of behavioral changes and degradation of central nervous system performance due to low intensity exposure. Some evidence of nonthermal effects has been submitted. There has been disparity among many scientists over the existence of the "pearl chain effect," in which particles form into chains parallel to the electric lines of force.

Lebovitz has theorized that a thermal effect may result from resonance absorption in the semicircular canals in the labyrinth in the inner ear at a power density of about

10 mW/cm^2 or less, currently thought not to produce thermal effects. (12) The clinical technique of vestibular stimulation is used in the ear with water slightly warmer than the local tissue, resulting in vertigo, ocular nystagmus, and other effects. The caloric stimulation proposed by Lebovitz, then, could account for the behavioral and neurophysiological phenomena consistent with the nonthermal effects claims.

Frey substantiated Russian claims that microwave exposure elicited specific effects in the auditory system. (8) At intensities as low as 100 μW/cm^2 and with the ears plugged to eliminate the normal hearing channel, the subjects sensed the radiations and perceived them as a clicking, whistling, or humming sound depending upon the experimental circumstances. Frey believed that the radiation directly stimulated the neural receptors in the inner ear. The most sensitive area of the brain was the temporal lobe. The response was greatest in the frequency range from 300 MHz to 1.2 GHz. Sommer and Von Gierke concurred with Frey's findings, but suspected that the auditory response resulted from electromechanical conduction by air or surrounding bone, that stimulated the cochlea as opposed to direct stimulation of the neural receptors there. (29)

The Federal Drug Administration's Bureau of Radiological Health has been conducting research concerning the low level effects on the body from radio frequency and microwave exposure and especially those on the central nervous system.

Preliminary findings indicate "loss of learned behavior and loss of brain-wave activity" in monkeys. (6) Also found was a quicker onset of the development of cataracts in genetically cataract-prone mice. The tests were not statistically conclusive though because of the limited number of subjects used.

The White House Office of Telecommunications Policy was established with the objective to determine what effects occur in animals and humans from exposure to radiations of various frequencies and intensities and to establish a sound scientific basis for these effects. They have determined that "microwaves, radiowaves, and electrical fields can effect the nervous system, behavior, growth development, and possibly metabolism and body chemistry at levels lower than estimated in the past." (1) Once again these results are preliminary findings and not statistically and scientifically conclusive.

Korbel found rats to be lethargic, more emotional, and more prone to seizures after subjection to .15 mW/cm^2 irradiation of microwave frequencies. (1) In further studies the rats demonstrated cumulative signs of learning disability.

An unusual phenomenon was demonstrated by Culken and Fung. (1) They found that bacteria were killed at a higher rate in the cooler surface areas in microwave-cooked meat, as opposed to logical assumption that the greater internal temperature of the meat which is indicative of this type of cooking would most likely kill the bacteria more efficiently. They hypothesized that there might be some nonthermal effect

(even though the incident intensity in the oven is designed to produce the thermal effect of cooking meat) that killed the bacteria. Since our present understanding of the biological interaction involved is somewhat limited, this possibility can not be ruled out. Rosenthal, the present Chairman of the ANSI C95 Committee on RF Radiation Hazards, admits that there is a "serious lack of knowledge regarding the biological effects of microwaves." (24)

A nonthermal biological effect that is significant in the United States deals with an indirect effect that is detrimental to the health of a small minority of Americans. These radiations have caused interference and degraded performance in some types of cardiac pacemakers. (25) The demand type has been vulnerable to these radiant energies. Research is in progress to shield the pacemakers and put an end to this indirect nonthermal effect.

CONCLUSIONS

The existence of nonthermal biological effects in humans from exposure to low level intensities of radio frequency and microwave radiations is an accepted reality in the Soviet Union and some Eastern European countries to such an extent that their personnel protection standards for the health and safety of occupationally exposed workers are based on this premise. They feel that these detrimental effects are an appropriate measure of the hazard to health from these radiations.

At an intensity as low as .01 mW/cm^2 the resulting biological effects have been declared as relevent enough to establish the exposure standard level. For the most part the effects are psychological in nature and are not as reproducible in collaborating experimentation as are physiological alterations in body tissues, organs, or systems. Thus far, the study of Russian research has not shown these effects to be of sound scientific basis.

There is need of further research to replicate or repudiate the Russians. However, recent research in the United States has found some existence of these effects. Therefore, the claim of nonthermal effects may significantly relate to the relevance of the second question in the introduction concerning the possible detrimental effects from chronic exposure to these radiations at low level irradiation intensities that may affect and injure our future health or that of coming generations. The next chapter will examine the biological effects and then assess the quality of the ANSI standard in terms of these effects.

CHAPTER V

PROPOSED ANSI C95.1 EXPOSURE STANDARD

Introduction

As pointed out in the discussion on thermal effects, the current maximum recommended exposure level that is specified in ANSI C95.1 has proved to have been successful in that there has not been any documented adverse health effects resulting from exposure within the specified limit. Thus, it appears that there need not be any changes to this standard since there has not been any evidence presented to blemish its effectiveness.

The level of 10 mW/cm^2 that was adopted by the American National Standards Institute was originally intended over twenty years ago for exposure in the occupational environment. Background radio frequency and microwave levels were less then, and personnel working with these radiations were aware of the source that they would be exposed to on the job. The size of the exposed group of individuals was relatively small then.

With the continuing phenomenal rise in the use of these radiant energies in the home and for other commercial purposes along with the same trend in industry and the military, there is widespread exposure to low level fields in these bands as

there never was. ANSI has undoubtedly taken into consideration that the potential risk is increasing, in examining the quality of its existing guideline during its updating of the standard. With the size of the group of persons exposed to these frequencies rising to higher levels than ever before, it seems appropriate to interpret the present standard in view of its quality and effectiveness for preventing biological damage.

Relevant Biological Effects

The preceding two chapters summarized the pertinent aspects regarding the findings from research done on the effects on our health from radio frequency and microwave radiations. Thermal effects have been researched and documented to a satisfactory degree such that the thresholds for detrimental and acute health effects have been putatively established. The ANSI explanation of the degree of severity of thermal effects resulting from the variance in exposure about the maximum recommended level appears to be a reliable expression of the relative severity of thermal effects in terms of a dose-response relationship. ANSI states "radiation characterized by a power level tenfold smaller will not result in any noticeable effect on mankind. Radiation levels which are tenfold larger than recommended are certainly dangerous." (26)

Nonthermal effects detrimental to health have been persistently advocated by Russian and Eastern European sources. Recent research in the United States at low levels of radiation

has shown a variety of effects; however, no results have been significant enough to relinquish the belief that thermal effects are the only effects serious enough to be considered hazardous to health. Thus, in terms of the two initial questions regarding the possible deleterious health effects from acute exposure and the possible late-arising health effects from chronic low level exposure, it appears that the answer to the first question has been satisfactorally decided upon. The answer to the second question is still controversial and needs further research before a settlement to this issue can be made.

Exposure to Significant Power Levels

Before proceeding to an examination of the effectiveness of the present standard, it is worthwhile to review the incident power levels at which these biological effects occur and evaluate the potential risk of being subjected to these levels. An important point to remember is the determination of an exposure standard is an objective process and influence of the risk of exposure should not affect the protection standard. It is only a statement of the dose-response relationship of the radiant energy and resultant biological effect.

The incident power density level for thermal effects to occur begins at approximately 10 mW/cm^2. The E field is 194 V/m at this level. Since the existence of nonthermal effects has not been conclusively denied, it is important to

recall and bear in mind their threshold power density level. The Soviet standard shows that nonthermal effects may result as low as .01 mW/cm^2. The E field is 6 V/m at this level. The power density is the intensity of energy flow per unit area found by taking the time average of the Poynting vector and using the intrinsic impedance of the medium, Z_o, which is 377 ohms for free space. Therefore, power density equals

$$E^2/Z_o \quad \text{(for rms values of E).}$$

Example: 194 V/m = 1.94 V/cm, and (1.94 V/cm)^2/377 = .01 W/cm^2 = 10 mW/cm^2.

The danger of being exposed to harmful levels of nonionizing energy in this region of the electromagnetic spectrum is becoming more a reality. Population centers are the most likely to be subjected to potentially dangerous levels of radiation. In the larger cities there are many broadcast stations for radio and television. In New York City, for example, there are eight AM radio stations alone broadcasting at the maximum power of fifty kilowatts. A fifty kilowatt AM station broadcasting with an omnidirectional antenna produces an E field component of 1 V/m at one mile, .1 V/m at ten miles, and .01 V/m at twenty miles. (31) The figures can vary considerably but are typical values of field strength at these distances. Stations with directional antennas even radiate stronger signals. If the eight stations were all monopole broadcasts from the same point, a field of 8 V/m could be set up at a radius of one mile, in comparison to the

Soviet standard for these radio frequencies of only 20 V/m.

Exposure from FM radio and television broadcasts can be calculated from the formula

$$E = \sqrt{30P_t}/R$$

where P_t is the transmitter ERP in watts and R is the distance in meters from the antenna. (31) Operating at maximum ERPs, these broadcasts radiate a signal with an E field at a distance of one mile from the antenna of 7.65 V/m for UHF TV stations, 1.92 V/m for high band TV stations, and 1.08 V/m for low band TV and FM radio stations. The figures are applicable to the main beam of the antenna broadcast pattern and would not be representative of a ground level point. The importance of these intensities exists in situations where tall buildings are in the vicinity of the broadcast tower. Corrected figures with respect to the ground at one mile would be 1.02 V/m for FM radio, .81 V/m for low band TV, .19 V/m for high band TV, and .38 V/m for UHF TV. (31) Along with AM radio, these broadcast bands represent low level electromagnetic radiation in many cities where there are numerous commercial stations.

An owner of a microwave oven can be subjected to a field with a power density of 5 mW/cm^2 (137.3 V/m electric field strength). The performance standard, as specified by the Radiation Control for Health and Safety Act of 1968 (PL90-602), for the maximum leakage permitted throughout the useful life of the oven allows for up to 5 mW/cm^2 at a distance of five centimeters from external oven surfaces. (19) A Public Health

Survey, taken in 1969 just before the microwave oven standard was established, showed that over twenty-five per cent of the ovens that were inspected leaked greater than 10 mW/cm^2 at a distance of more than five centimeters away. (3) Leaks around the door were most prevelent from lack of cleaning and maintenance. The many sources of nonionizing radiation in the radio frequency and microwave bands will continue to increasingly expose many individuals, and the danger of being exposed to at least what Russian scientists believe is harmful may become a reality in the future.

Effectiveness of ANSI C95.1

Although consideration of the potential risk involved by exposing a larger portion of the population is a necessary concern, the adverse effect in the health of the people is a direct measure of the merit of the thermal and nonthermal biological effects. The lack of sound scientific data to acknowledge that nonthermal effects exist and are harmful in mankind has precluded the American National Standards Institute from basing the C95.1 standard--Safety Level of Electromagnetic Radiation with Respect to Personnel--on any effects other than those producing thermal damage in man. Therefore, in an evaluation of the quality and effectiveness of this standard the predominant concern is whether proper protection is afforded, based on this premise, to personnel by following the present standard. With respect to the various expressions for the amount of exposure a person can be subject

to without violating the standard, it appears that this standard is completely satisfactory in the specified frequency range.

The scope of the standard originally involved determining the "hazards to mankind . . . created by man-made sources of electromagnetic radiation. The frequency range of interest extends presently from 10 kHz to 100 GHz." (26) For the frequencies of interest in this paper the radio frequency band of the spectrum starts at 30 kHz. The lower limit of the frequencies specified in the standard is 10 MHz. ANSI considers that there exists no amount of radiation exposure that would result in biological damage in the range from 10 kHz to 10 MHz.

The absorption of energy resulting in an increase of the thermal state of the tissue irradiated does drop off rapidly as the frequency decreases. Thus, for a thermal effect to result the incident power level would have to be orders of magnitude larger than that needed for the higher frequency waves. But to completely ignore this frequency range implies no effect, thermal or otherwise, would occur that is detrimental to health.

A standard should provide an adequate summary of the hazard it is supposed to protect against. The standard does provide a minimum of discussion expressing the basic ideas justifying its existence, but the "explanation" of the standard is too brief and inadequate. The recommendations for

revisions to the ANSI C95.1 standard will delve further into this problem by correcting the first deficiency regarding the applicable frequency limits and also the second by expanding the scope of the "explanation."

Extending the Frequency Range of ANSI C95.1

The first change necessary to improve the effectiveness of the current standard is to decrease the lower bound of the frequency range to at least 10 kHz, even though 30 kHz was specified to be the lowest frequency in the radio frequency band in this paper. An implication of the safety level with respect to electromagnetic radiation extends far below this frequency but is not of concern here. ANSI considers the spectrum to be divided such that radio frequency waves exist in the spectrum from 10 kHz to 300 MHz and that microwaves exist from 300 MHz to 100 GHz. (30) This is the reason why the lower limit was dropped to 10 kHz and not 30 kHz.

The maximum exposure level to safely protect personnel in the bandwidth from 10 kHz to 10 MHz could be an extension of the 10 mW/cm^2 level to cover these frequencies. Of course, this guideline would be more correctly expressed in terms of the electric field strength such that 194 V/m would be the meaningful exposure level. Tell suggested this in his writing so that the lower frequency waves would at least be covered by the standard. (31)

The maximum exposure level could be adjusted accordingly up to the point where thermal effects might theoretically

occur based on a calculation of the absorption coefficient. The level also might be set by empirical studies from experiments on phantom models of various dielectric absorbers of different geometries as done by the Admiralty Surface Weapons Establishment in England. (23) Their studies led to the value of 1000 V/m for frequencies below 30 MHz based solely on induced thermal effects. With such a gross electric field, however, the point at which a detrimental health effect occurs is probably at a much lower intensity. The effect might not be biologically damaging in the consideration of an irreversible change, but psychological and behavioral problems in the exposed individual could present a great danger. Job performance or even daily routine could be interfered with to such a degree that the danger of even minor, controlled hazards on the job or in the environment might be increased. The possibility of reversible nonthermal effects losing their reversibility is a much greater hazard.

In summary, the current standard must be extended to cover the lower frequencies (down to at least 10 kHz), but at what level of exposure to be set as the maximum recommended level must still be determined. Research on what effects, what consequences from these effects, and what electric field strengths or maybe even magnetic field strengths produce the effects, is still needed especially in an analytical or theoretical sense for justification and reproducibility. The lowest intensity at which a sensitive person would be susceptible should be designated in the research.

Expanding the Scope of the Explanation of the Standard

The second change necessary to improve the effectiveness of the standard is to expand the scope of the "explanation," presented with the exposure levels to elucidate or explain their necessity for existence. A satisfactory discussion of the basis of the standard, the consequences of overexposure, and the possible, but not-confirmed effects is definitely warranted for an effective standard.

In less-controlled exposure situations knowledge of the basis of the standard and the effects of exceeding the guide numbers can be very beneficial. The standard explains that exposure to these nonionizing radiations is "but one of several sources of heat input into the body." There is no statement as to even how much heat can be generated at an intensity equal to the guide number. To be included in the discussion to elucidate this point should be the amount of heat generated and the resultant temperature rise. For example, biologists believe that it is undesirable to increase the internal body temperature at a rate greater than the normal metabolic rate of approximately 5 mW/cm^2 on a body surface area basis. (31) For an average-size male with a body surface area of two meters then about fifty watts of heat would be produced during whole body irradiation. This compares closely with Mumford's value of 57.5 watts, with a temperature elevation of 1 $^{\circ}C$. (18) These and the following recommendations are necessary for the user of the standard to

have a fundamental knowledge of the hazard for which the standard is designed to protect against.

With regard to thermal stability the standard states "body temperature depends in part on sources of heat such as electromagnetic radiation, physical labor, high ambient temperature, and on heat dissipation capability, as affected by clothing, humidity, etc." To further clarify this, it is noteworthy that thermal abuse from an electromagnetic source on a whole body basis is indistinguishable from a typical fever. The circulatory system along with the entire thermoregulatory system responds as such. The standard points out a note of caution regarding this point, that "people who suffer from circulatory difficulties and certain other ailments are more vulnerable." It should specifically relate this to a degradation of the body's heat dissipating capability though.

In a similar sense, the parts of the body that lack thermal sensitivity or thermal homeostatic capability deserve particular attention. As pointed out in the thermal effects discussion, the eye, testes, gall bladder, and parts of the gastrointestinal system are susceptible organs. The standard only states "partial body irradiation must be included since it has been shown that some parts of the human body (for example the eyes or testicles) may be harmed if exposed to incident radiation levels significantly in excess of the recommended levels." It has said nothing of the reason why this would occur or what exactly might occur.

An important point that has also been disregarded is that these organs may be severly stressed in a thermal sense without a significant rise in the body's oral or rectal temperature. A special precaution in the standard should alert the reader or user of this fact.

A factor that contributes to the basis for a fuller understanding of the application of the standard in a particular exposure situation involves the thermal characteristics of the environment. The standard explains the influence of the environment as "the guide numbers are appropriate for moderate environments. Under conditions of moderate to severe heat stress the guide numbers given should be appropriately reduced. Under conditions of intense cold, higher numbers may also be appropriate after careful consideration is given to the individual situation." Ideally, a quantitative alteration of the standard should be formulated to account for variations in the environment such as temperature and humidity.

Mumford has proposed that the guide number be lowered to a level of 80 - Temperature-Humidity Index (THI), for a THI between 70 and 79; lowered even further to 1 mW/cm^2 for a THI $\geq$ 80; and kept the same for a THI $<$ 70. (18) His reasoning is that this would alleviate the thermal stress to some degree when the heat dissipating ability of the body is hindered. Its inclusion in the standard, however, would ignore "the ability of the body to adjust to considerable

fluctuations in ambient temperature and humidity with little or no strain." (17) The important question then is how much is "appropriately reduced" concerning the reduction in the guide number. The figure of 1 mW/cm^2 corresponds to the power density level that does not produce thermal effects. (17) That would surely be appropriate enough. Thus, a further clarification to specify the quantitative alteration of the standard under worst case conditions should be formulated.

The many variables involved in an exposure situation are definite factors in the thermal stress induced in the individual. The standard covers this by stating "sufficient information concerning modulation effects, peak power effects, field strength effects, or frequency dependencies and limits is not currently available to substantiate adjustment of the radiation protection guide to account for these effects." This statement alerts the user of possible peculiar situations involving any of the above factors even though nothing positive is said about them, and is an example of some of the fundamental considerations that must be examined in an individual exposure situation. Concerning frequency dependencies, absorption is clearly frequency dependent.

The standard also states "that details of anatomy, the frequency of radiation, and its penetration affect the percentage of absorbed energy." Even so, further clarification should be presented. Inclusion of the following relevant specifics is worthwhile: greater absorption by tissue of high water content, considerably lesser absorption by tissue

of low water content, results of studies demonstrating the percentage absorption, and finally results from similar studies on tissue penetration as related to frequency. Cleary showed that absorption ranged from ten per cent of the incident energy at 10 MHz to seventy per cent at 100 GHz in high water tissue. (4) Adding the recommendations in the preceding discussion would expand the scope of the "explanation" such that the fundamental ideas necessary in understanding the basis of the hazard involved are presented. The "explanation" would still be relatively short, but would be considerably more effective than the current one.

The ANSI explanation of the consequences from overexposure is that at the level of 100 mW/cm^2 these radiations are "certainly dangerous." Prior knowledge of the possible consequences from inadvertent or uncontrolled exposure to these radiant energies must be understood in a situation where the risk is appreciable. A statement of the known effects should be presented to evaluate the danger involved where high intensity fields may be encountered. The standard is inadequate if this is not accomplished.

A minimum summary of health effects would include the possibility of cataract formation at intensities as low as a tenfold multiple of the guide number. Documented cases of this injury have shown this to be a significant health risk. As previously mentioned, an artifically induced fever will result. This effect should be clearly expressed in the discussion of consequences resulting from overexposure. The

possibility of temporary and reversible sterility in male subjects should be warned against. Finally, the irreversible damage from cell and tissue failure from thermal abuse should be the ultimate warning. These concepts are not meant as a scare tactic, but are necessary in order to estimate a reasonable appraisal of the hazard from minor to gross over-exposures.

In terms of exceeding the guide number of 10 mW/cm^2, the standard does allow such an excursion with the constraint that an average dose is not exceeded during any .1 hour. The average dose is 1 mWh/cm^2. Thus, the maximum recommended guide level could be tolerated for six minutes in one hour. This allowance for exposure in excess of the guide number should be re-emphasized in the "explanation" for clarity.

The final topic to be included in the expansion of the scope of the "explanation" is the hazard of possible nonthermal biological effects. Since these effects have neither been confirmed or ruled out, a short precautionary summary of their proclaimed manifestations should be presented as well as their occurrences at power density levels well within the present maximum exposure limit. Symptoms of the nonthermal effects should be stated as likely signs of nonthermal stress. These include headache, irritability, unusual drowsiness, and other asthenic conditions. Elevation of the threshold of the auditory and olfactory senses may also occur. Although these effects are reversible in nature, irreversibility must be considered as a consequence from overloading or fatigue of the

interaction process. Until such time that nonthermal effects are accepted as valid indications of biological damage and present standards are revised downward, or the effects are disproven, a necessary warning should be stated.

Summary

The ANSI C95.1 standard has been evaluated in view of recent research done on discovering the harmful biological effects from radio frequency and microwave radiation. The risk of exposure to fields with conceivably hazardous implications is also discussed. The guide numbers in the standard are of a satisfactory magnitude with over twenty years use. The only numerical change proposed is an extension of the frequency boundary to cover the lower radio frequency waves. The other proposal for improving the standard involves providing an adequate evaluation of the exposure hazard, which is inadequate in the current standard.

CHAPTER VI

CONCLUSIONS

The expanding use of the electromagnetic spectrum in terms of increased applications and radiated power levels has brought about vast progress in our society. The progress must be measured against the potential hazards which it may have created. The ever increasing use of radio frequency and microwave propagations can not continue without giving adequate reflection about what possible adverse biological effects may arise.

Modern research is still studying the biological effects in consideration. Thermal effects are now largely understood although the theoretical interactions can not be fully explained. As previously pointed out, this occurs since biological tissue is very complex structurally and determination of the wave configuration within has yet to be made. Dielectric tissue properties have accounted for the understanding and degree of thermal inducement, but the physiological alterations inside the tissue, if any, can not be accounted for. The proclaimed nonthermal effects constitute a similar problem regarding the lack of a theoretical explanation of their origin through any interaction processes. They are much less understood, especially in this country. The

lack of scientifically solid research results for reversible and specific changes relating them as hazardous to health has prevented U.S. authorities from revising existing standards downward to accomodate for them. Chapters III and IV have reviewed the research and findings concerning the present status of biological effects resulting from exposure to the electromagnetic radiations in question.

The American National Standards Institute has published C95.1 in fulfillment of its role to determine and prevent "possible harmful effects on mankind . . . originating from radio stations, radar equipment, and other possible sources of electromagnetic radiation such as used for communication, radio-navigation, and industrial and scientific purposes." (26) The effectiveness of the standard in terms of its widespread application has found it to be subsequently accepted for use by the Occupational Safety and Health Act (OSHA) of 1970. OSHA applies the standard to occupationally exposed individuals.

The American Conference of Governmental Industrial Hygienists (ACGIH) has also adopted the basic ANSI standard with slight modifications to express safe levels for continuous, intermittent, and ceiling exposures. The ACGIH threshold limit values also apply to occupationally exposed individuals.

The proposed revisions formulated in the preceding chapter have been made to increase the effectiveness and

applicability of the C95.1 standard. Since the only numerical change involved extending the frequency limits, this is the only implication that would have any profound effect on the exposure limits now used.

Guidelines for future research on this topic have been presented throughout this paper. One additional need not mentioned thus far is for a standardized system for precise and accurate measurements of field strengths under many varying circumstances. With such, credible data can be taken and used in formulating a standard that is backed up with accurate and reproducible data. Until such time that the settlement can be made in determining the full implications of the biological effects resulting from exposure to radio frequency and microwave radiations, research must continue and caution and control must be exercised in exposure situations.

LIST OF REFERENCES

1. Arehart-Treichel, J., "Electromagnetic Pollution: Is it Hurting our Health?" <u>Science News</u>, Vol. 105, No. 26, June 29, 1974.

2. Carpenter, C.M., Page, A.B., <u>Science</u>, Vol. 71, 1930.

3. Cheever, C.L., "Microwave Radiation: Hazards and Controls," <u>National Safety News</u>, December 1974.

4. Cleary, S.F., "Biological Effects of Microwave and Radiofrequency Radiation," <u>CRC Critical Rev. in Environmental Control</u>, Vol. 1, No. 2, June 1970.

5. Cochran, M., "'Smokey Bear' CBer's Keep Him Spotted," Associated Press, <u>Texarkana Gazette</u>, September 27, 1975.

6. "Consequences of Effluent Release," <u>Nuclear Safety</u>, Vol. 15, No. 2, March-April 1974.

7. Electromagnetic Compatability Analysis Center, Department of Defense, VICA Environmental Displays, North Severn, Maryland, May 17, 1971.

8. Frey, A.H., "Human Auditory System Response to Electromagnetic Energy," <u>Journal of Applied Physiology</u>, Vol. 17, 1962.

9. Herrick, J.F., Krusen, F.H., "Certain Physiologic and Pathologic Effects of Microwaves," <u>Electrical Engineering</u>, Vol. 72, 1953.

10. "How Unseen Microwaves are Changing Your Life," <u>U.S. News & World Report</u>, December 9, 1974.

11. Johnson, C.C., Guy, A.W., "Nonionizing Electromagnetic Wave Effects in Biological Materials and Systems," <u>Proceedings of the IEEE</u>, Vol. 60, No. 6, June 1972.

12. [illegible], R.L., "[illegible] via UHF-Microwave Irradiation," <u>IEEE Transactions on Biomedical Engineering</u>, Vol. BME-20, No. 2, March 1973.

13. Letavet, A.A., Gordon, Z.V., The Biological Action of Ultrahigh Frequencies, Institute of Labor Hygiene and Occupational Diseases, Moscow, 1960.

14. Matelsky, I., "Non-ionizing Radiations," Industrial Hygiene Highlights, Vol. 1, 1968.

15. Michaelson, S.M., Biological Effects and Health Implications of Microwave Radiation, U.S. Government Printing Office, Washington D.C., 1970.

16. Michaelson, S.M., "Human Exposure to Nonionizing Radiant Energy-Potential Hazards and Safety Standards," Proceedings of the IEEE, Vol. 10, No. 4, April 1972.

17. Michaelson, S.M., "Standards for Protection of Personnel against Nonionizing Radiation," American Industrial Hygiene Association Journal, December 1974.

18. Mumford, W.W., "Heat Stress due to R.F. Radiation," Proceedings of IEEE, Vol. 57, No. 2, February 1969.

19. Performance Standard for Microwave Ovens, Federal Register, Vol. 36, No. 195, Title 42, Part 78, October 6, 1970.

20. Petrov, I.R., Subbota, A.G., "Influence of Microwave Radiation on the Organism of Man and Animals, Meditsina Press, Leningrad, 1970; NASA TT F-708.

21. Presman, A.S., Electromagnetic Fields and Life, New York-London, Plenum, 1970.

22. Presman, A.S., Levitina, N.A., Bull. Exp. Biol. Med., Moscow, 1962.

23. Rodgers, S.J., "Radio Frequency Radiation Hazards to Personnel at Frequencies below 30 MHz," Biological Effects and Health Implications of Microwave Radiation, U.S. Department of Health, Education, and Welfare, September 1969.

24. [illegible], "Biological Effects of Nonionizing Radiation," IEEE Transactions on Biomedical Engineering, [illegible] 19[illegible]

25. Ruggera, P.S., Elder, R.L., Electromagnetic Radiation Interference with Cardiac Pacemakers, U.S. Department of Health, Education, and Welfare, 1971.

26. "Safety Level of Electromagnetic Radiation with Respect to Personnel," American National Standards Institute, C95.1, 1974.

27. Schereschewsky, J.W., Radiology, Vol. 20, 1933.

28. Schwan, H.P., Li, K., Proceedings IRE, Vol. 41, 1953.

29. Sommer, H.C., Von Gierke, H.E., "Hearing Sensations in Electrical Fields," Aerospace Medicine, Vol. 35, 1964.

30. "Techniques and Instrumentation for the Measurement of Potentially Hazardous Electromagnetic Radiation at Microwave Frequencies," American National Standards Institute, C95.3, 1973.

31. Tell, R.A., "Broadcast Radiation, How Safe is Safe?" IEEE Spectrum, August 1972.

32. Tyler, P.E., "Overview of the Biological Effects of Electromagnetic Radiation," IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-9, No. 2, March 1973.

33. Wilkening, G.M., "Nonionizing Radiation," The Industrial Environment-Its Evaluation and Control, National Institute of Occupational Safety and Health, 1973.

34. Zaret, M.M., "Clinical Aspects of Nonionizing Radiation," IEEE Transactions on Biomedical Engineering, Vol. BME-19, No. 4, July 1972.